Review

Can we Strengthen the Anterior Cruciate Ligament with Passive Knee Joint Loading?

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Citation: Jelen M, Vahnik R. Can we Strengthen the Anterior Cruciate Ligament with Passive Knee Joint Loading? Proceedings of Socratic Lectures. **2025**, 12(II), 174-177. https://doi.org/10.55295/PSL.12.2025.II18

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Abstract:
Passive knee joint loading has been proposed as a safe method to enhance knee stability during early postoperative rehabilitation following anterior cruciate ligament (ACL) reconstruction. However, its effects on anterior and mediolateral rotational laxity remain unexplored. Evaluating whether passive knee joint loading in the direction of anterior tibial translation improves knee stability post-surgery is essential. Current research primarily focuses on active loading, such as quadriceps strengthening exercises, but concerns about excessive anterior tibial translation and graft compromise make early postoperative loading controversial. Our review builds on previous studies on passive knee joint loading in healthy individuals and post-ACL reconstruction cases. Unlike active loading, passive anterior tibial translation via the DYNEELAX® arthrometer enables controlled mechanical stimulation within a safe force range, potentially aiding early graft adaptation. Preliminary findings suggest passive loading could be a valuable addition to ACL rehabilitation, though further research is needed to determine optimal parameters such as force magnitude, frequency, and duration. Methodological challenges complicate the study of passive loading in clinical trials. Future research should focus on integrating controlled passive loading into rehabilitation protocols while distinguishing its contribution to recovery. Understanding the biomechanical effects of passive loading will help refine ACL rehabilitation and broader musculoskeletal treatment strategies, ultimately improving long-term knee stability and reducing graft failure risk.

Keywords: Knee; ACL reconstruction; Passive loading; Stability; Postoperative rehabilitation; Joint mechanics

Introduction

In Slovenia, we initiated research to determine whether passive loading of the knee joint affects its stability in healthy women (Vauhnik et al., 2015). In this study, physiotherapists applied anterior translation forces of 100 N and 170 N to the knee joint, and the results showed no statistically or clinically significant effect on knee joint stability. This remains the only published study investigating the effects of passive knee joint loading in healthy individuals. Regarding anterior cruciate ligament (ACL) injuries, two case studies have been published (Rugelj et al., 2021a; Rugelj et al., 2021b), whereas no studies have yet explored the effects of passive knee joint loading on its stability in participants following ACL reconstruction surgery.

In contrast, research on active knee joint loading provides insight into its effects on knee stability. Barcellona et al. (2015) found that active knee loading through quadriceps strengthening exercises in an open kinetic chain improved knee joint stability in participants with acute ACL injuries. The group performing exercises involving anterior tibial translation demonstrated statistically and clinically significant reductions in knee joint laxity compared to the control group. Similarly, Perry et al. (2005) investigated the effects of quadriceps strengthening exercises in an open kinetic chain on knee joint loading in participants following surgical ACL reconstruction. Loading initiated 8 weeks postoperatively, applying a force of 270 N, did not increase knee laxity.

Mechanical loading is essential for maintaining and adapting the structural, histological, and functional properties of connective tissue (Kjaer, 2004; Woo et al., 2006). Exposing the newly reconstructed ACL to controlled mechanical loading before 8 weeks postoperatively is critical for its functional adaptation. However, excessive loading may overstress the graft, highlighting the need for a carefully regulated approach. One of the primary forms of mechanical loading is anterior tibial translation, which can be applied either passively (e.g., manually via the Lachman test or instrumentally using knee arthrometers such as KT1000, KT2000 and DYNEELAX®) or actively (through quadriceps strengthening exercises in an open kinetic chain). Morrissey et al. (2009) reported that loading forces between 160 N and 850 N improve knee stability, while forces exceeding 850 N increase laxity and may lead to instability.

Knee joint stability, a key indicator of successful ACL reconstruction, should be assessed through a combination of patient-reported stability and objective measurements using knee arthrometers such as the DYNEELAX® **(Figure 1)**. This device has demonstrated high intra-rater reliability (Mihalinec et al., 2024; Nascimento et al., 2024) and excellent inter-rater reliability (Mihalinec et al., 2024), reinforcing its value in clinical practice.

The DYNEELAX® arthrometer allows for the precise determination of anterior knee laxity, measured in mm/N. The results are presented as a force-displacement curve **(Figure 2A)**, where the slope represents the tensile strength of the ligament. Additionally, mediolateral rotational laxity is quantified in °/Nm and displayed as a torque-angle curve **(Figure 2B)**, with the slope similarly reflecting the ligament's tensile strength (Genourob, n.d.).

Figure 1. The DYNEELAX® arthrometer set up to measure the laxity of the right knee joint (Genourob, n.d.).

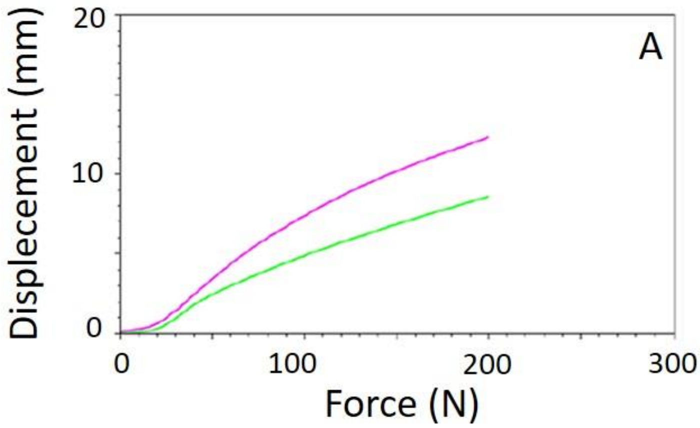

Figure 2. A: Force-displacement curve for anterior knee joint laxity obtained from the DYNEELAX® arthrometer. **B:** Torque-angle curve for medial rotational knee joint laxity obtained from the DYNEELAX® arthrometer. The pink line represents a pathological knee joint, while the green line indicates a healthy knee joint (Genourob, n.d.).

A critical component of ACL rehabilitation is the identification of safe and effective loading strategies that facilitate graft adaptation. The early postoperative phase is particularly sensitive, as excessive anterior tibial translation can compromise graft integrity. As a result, active loading exercises—such as quadriceps strengthening in an open kinetic chain—are typically avoided during the first eight weeks postoperatively. This limitation highlights the need for alternative approaches, with passive loading emerging as a promising strategy for controlled mechanical stimulation.

Passive loading may provide sufficient mechanical stimulation to promote the functional adaptation of the ACL graft while minimizing the risk of excessive strain or graft failure, thereby contributing to a reduction in knee joint laxity. Unlike active loading, which imposes high forces on the graft, passive anterior tibial translation using the DYNEELAX® arthrometer enables controlled application of mechanical stress, ensuring gradual exposure within a safe range. If validated by future research, these findings could support the incorporation of passive knee joint loading into early rehabilitation protocols, helping to refine post-surgical treatment strategies, optimize outcomes, and reduce the risk of graft failure and other postoperative complications.

Taken together, these findings highlight the importance of further research into passive loading as a potential strategy for enhancing ACL rehabilitation. Determining the optimal parameters—such as force magnitude, duration, and frequency—will be crucial for safely integrating passive loading into clinical practice. Given the ethical constraints of clinical studies, it would not be ethically appropriate to implement passive loading alone within rehabilitation protocols. Future research should focus on rehabilitation programs that incorporate controlled passive loading, ensuring that its effects are distinguished from other therapeutic interventions. This approach would allow for a comprehensive understanding of passive loading's potential role while maintaining ethical standards and patient safety in clinical settings.

Investigating the role of passive knee joint loading not only holds promise for improving post-ACL reconstruction outcomes but also contributes to a deeper understanding of knee joint biomechanics and the optimization of rehabilitation strategies for other musculoskeletal conditions. Addressing these gaps through well-designed studies will help establish evidence-based guidelines that enhance clinical decision-making. Ultimately, each new insight in this field represents a step toward more effective and safer rehabilitation, improving long-term knee stability and reducing the risk of re-injury.

Funding: The authors acknowledge the financial support from the Slovenian Research Agency (research core funding no. P3-0388 and BI-US/24-26-60).

Conflicts of Interest: The authors declare no conflict of interest.

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